ON WAFER THERMAL INVESTIGATION OF GAAS-BASED MICROWAVE TRANSISTORS BY A THERMOELECTRIC SYSTEM

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ABSTRACT

On wafer thermal analysis is of basic importance to assess key aspects of the performance and the reliability of microwave devices and circuits in a critical operation environment. To this aim, we have designed and realized an efficient Peltier-stage thermal chuck for on wafer microwave probe stations working over the 220 K – 320 K temperature range. Extensive testing has enlightened its features in terms of fast settling time and accurate temperature control. The performance of the system has been exploited in measurement of I-V curves, scattering parameters and noise figure up to 40 GHz of several microwave devices.
We here describe the details of the measurement system and present the results of our most recent experimental activity.

INTRODUCTION

The investigation of the effects of temperature upon the performance of transistors and circuits is a key issue in designing either hybrid or monolithic microwave integrated circuits (HMIC, MMIC) operating in a critical thermal environment. In addition, knowledge of the temperature-dependent characteristics supports evaluation of the device reliability against thermal transients as well as the occurrence of self-heating effects.
Following measurements, it is of great interest the extraction of noisy circuit models of the tested devices to determine the temperature dependence of the most important physical parameters. Accurate circuit models of the transistors are also basic tools for the computer-aided design of HMIC's and MMIC's by means of commercial microwave simulators.
We have already worked at the microwave characterization of packaged transistors in the 330 K to 230 K temperature range by investigating the linear noisy performance of packaged HEMT's with a commercial transistor text fixture enclosed in a conventional thermostatic chamber [1,2]. From the results obtained, we assessed the feasibility of applying a simplified procedure to extract the complete temperature-dependent noise performance of microwave FET's by performing only one noise figure measurement, [2].
This paper presents our newest experimental activity in this field, starting with the design and realization of the on wafer thermal chuck which is capable of a fine temperature regulation and a fast settling time within the 320 K to 220 K range as widely tested on several microwave devices.

DESIGN AND REALIZATION OF THE THERMOELECTRIC SYSTEM

Commercial thermal chucks for on wafer measurement systems typically employ a refrigeration/heating unit with close-circuit circulation of methanol alcohol. They often work in dry-gas flow conditions, which makes the temperature control slow and somewhat critical. Besides, they are characterized by high prices [3,4].

In order to meet our specifications in terms of lower cost and fast settling times, we designed and realized a current-controlled system based on a Peltier unit which allows for either cooling or heating the wafer.

In our system, there is a first thermal stage performing as an active heatsink to lower the temperature of the hot side of the Peltier cell by circulation of a cold ethyl-glycol solution. Such function is obviously employed only for low temperature measurements, whilst the main task is performed by the Peltier unit whose bias current level and polarity can be controlled to either lower or raise the temperature of the wafer piece under test.

The cell is glued by means of a silicon heat transfer compound to the heatsink; this is a brass plate soldered to a copper cooling coil containing the circulating solution. This part of the system is embedded in polyurethane foam and enclosed in a plexiglas structure with a window cut on the upper side of the Peltier unit.

The measurement set-up (i.e. the thermal stage with the probed wafer) is then isolated by means of a plexiglas cabinet where dry nitrogen is introduced to obtain a moisture-free environment, thus avoiding water condensation on the wafer at low temperatures.

This thermal chuck has high and low temperature limits of 350 K and 220 K, respectively. It maintains the operating value with an accuracy of ±1 K and has typical settling times less than 2 minutes for each 10 K step.

Use of a Peltier pump ensures a very good thermal performance by a proper drive and stabilization of the supply current. Improvement of the temperature performance is in progress by adopting optimized Peltier elements to cool down to 190 K.

TEMPERATURE-DEPENDENT CHARACTERIZATION OF ON WAFER DEVICES

By using the on-wafer thermal system, we have performed the DC and microwave characterization of MESFET's and HEMT's as a function of temperature from 320 to 220 K by measuring (a) scattering parameters up to 26 GHz for MESFET's and up to 40 GHz for HBT's and HEMT's, (b) noise figure up to 26 GHz for all device types.

A set of 0.25 μm-gate-length HEMT's (by Alenia Spazio, Italy) has been characterized down to 220 K at different bias levels (10, 20, 30 and 50% saturated drain current I_{dss}). It has been verified that the sensitivity to the temperature variations depends upon the bias current especially for the gain of the device, as evidenced by the polar diagrams of the S_{21} parameter.

For a series of 0.25 μm-gate-length pseudomorphic HEMT's (processed by Triquint foundry, USA) clear effects of self-heating mechanisms were evidenced by the DC characterization. Such effects, occurring in the saturation region as negative values of the output conductance, were more pronounced for longer gatewidth devices (900 μm) characterized by higher current values. The self-heating behavior was highly influenced by the measurement temperature as recognizable in the I-V curves reported in Fig.1, while no evidence was found in scattering parameters since the separation of the effects of self-heating and ambient temperature is very difficult to establish from microwave measurements performed only in CW conditions.

Also, GaAs-based HBT's (from TRW foundry, USA) were tested over the 300 K to 220 K range and they exhibited a regular behavior of the noise figure and the noise resistance, monotonically decreasing at lower temperatures. Such net effects is clearly explained by the increase of the gain and the decrease of the base resistance value by lowering the device temperature. The performance of the noise figure (6-26 GHz) of the TRW HBT's is reported in Fig.2.

As a final step, the experimental data were used to extract the noisy circuit model of the tested devices by means of a variable decomposition approach and noise figure fitting techniques [2]. A well-behaved temperature dependence has been exhibited by all major circuit elements as it will be detailed in the final paper.
Noise has been added to the small-signal circuit of HEMT's by adopting the Pospieszalski's model which considers only thermal contribution from all the resistors and reproduces high-field diffusion noise properties by over-warming the output drain-source resistor [5].
As far as the HEMT devices by Alenia Spazio are concerned, we here report the results of the temperature-dependent model extracted from measurements performed from 2 to 40 GHz at the bias point V_{ds}= 2V, I_{ds}= 4.5 mA (10% I_{dss}). The HEMT device transconductance shows a quite linear increase down to the lowest temperatures of about 0.133 mS/K which applies also to packaged devices we had previously tested down to 90 K by means of a cryogenic chamber. The input inductances L_G , L_S and the parasitic capacitances C_{IN} , C_{IO} are inversely proportional to the temperature, while the gate-source capacitance C_{GS} and the resistor contributions decrease by cooling the device. The comparison among measured and simulated data at 263 K is reported in Fig.3.

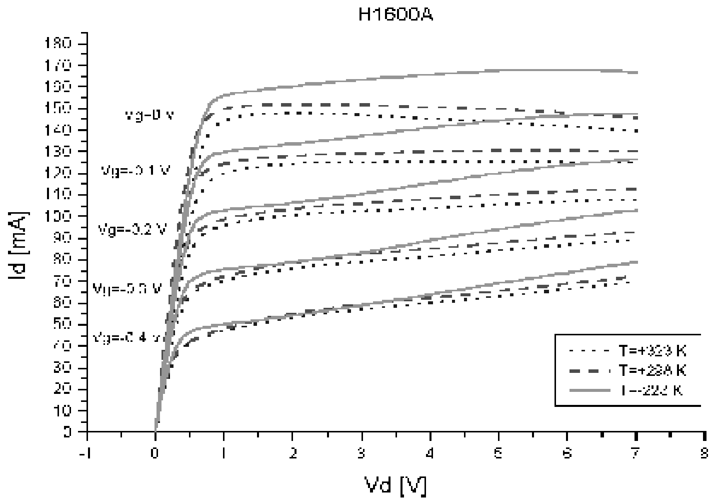

Fig. 1. I-V characteristics at 320, 290 and 220 K of the pseudomorhic HEMT's tested on-wafer. Self-heating effects are recognizable from temperature-dependent negative slope of the curves in the saturation region.

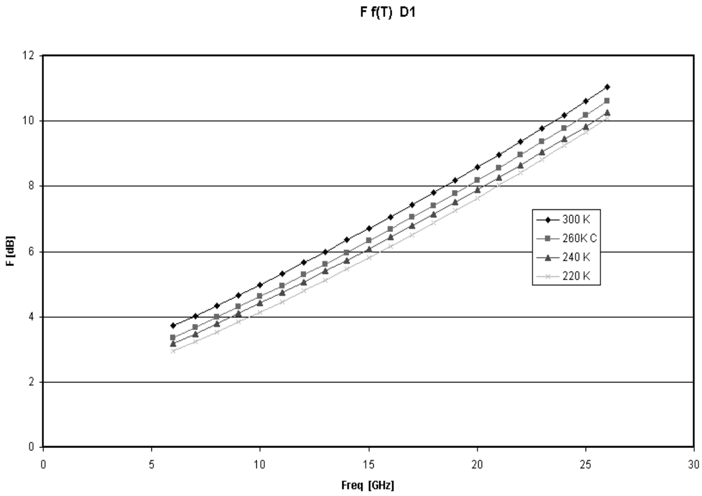

Fig.2. Performance of the noise figure (6-26 GHz) of AlGaAs/GaAs HBT's from 300 K to 220 K.

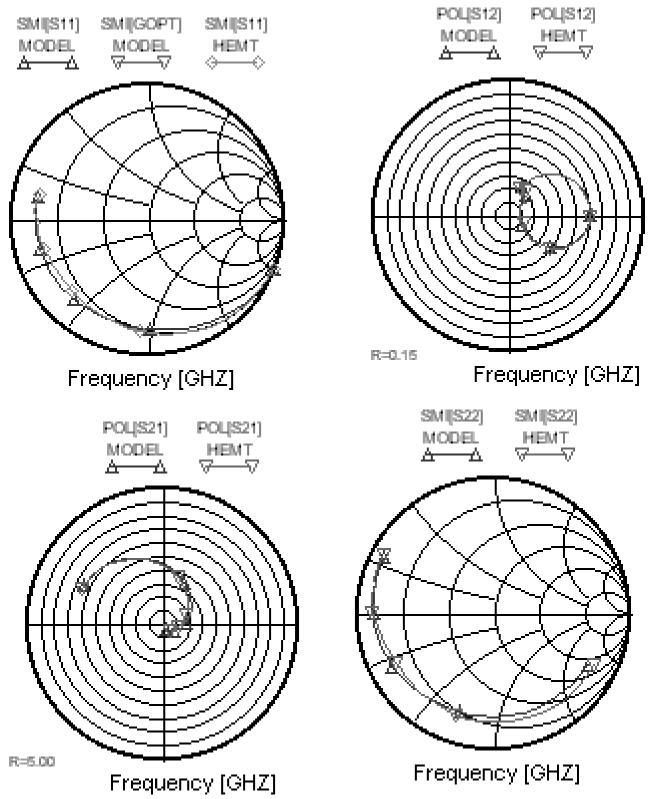

Fig.3. Comparison between measured and modeled scattering parameters of the HEMT tested at 263 K (10% I_{dss}) over the 2-40 GHz frequency range

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REFERENCES

[1] A. Caddemi, M. Sannino and G. Mogavero , "Temperature dependent noisy models of pseudomorphic HEMTs", *Int. J. Comp. Math. Electr. Electronic Eng.* , Vol.13, N.4, pp.807-815, Dec. 1994.
[2] A. Caddemi, A. Di Paola, M. Sannino, "Determination of HEMT's noise parameters vs. temperature using two measurement methods", *IEEE Trans. on Instrumentation and Measurement* , vol.IM-47 , pp.6-10, Feb. 1998.
[3] R. Anholt, S. Swirhum, “Experimental investigation of the temperature dependence of GaAs FET equivalent circuits”, *IEEE Trans. on Electron Devicess*, vol. ED-39,, pp.2029-2036, Sept.1992.
[4] S. Lardizabal, A. Fernandez, L. Dunleavy, “Temperature-dependent modeling of gallium-arsenide MESFET’s”, *IEEE Trans. on Microwave Theory Techniques*, vol. MTT-44, pp.357-362, March 1996.
[5] M. Pospieszalski, “Modeling of noise parameters of MESFETs and MODFETs and their frequency and temperature dependence”, *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-37, pp. 1340-1350, Nov.1989.